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(19)

(54) METHOD OF MILLING CURVED GROOVES

(71) We, GENERAL MOTORS CORPORATION, a Company incorporated under the laws of the State of Delaware, in the United States of America, of Grand Boulevard, in the City of Detroit, State of Michigan, in the United States of America (Assignees of HAROLD WILLIAM FERCHLAND) do hereby declare the invention for which we pray that a patent may be granted to us and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a method of milling curved grooves.

In the machining of grooves, an important factor to consider is the relationship of groove depth to groove width. For example, the depth-to-width ratio is determinative of whether a cylindrical end milling cutter and/or a circular flat milling saw or cutter can perform the necessary cutting operation, and cylindrical end cutters become less feasible with increse in depth-to-width ratio of the groove. Furthermore, when the groove is curved along its length the choice of milling cutter is even more limited since a circular' flat milling cutter overcuts the groove width on entry to and exit from the material to be cut. Such a compounded problem exists, for example, in the cutting of the side seal grooves in the rotor in the internal combustion rotary engine known as the Wankel engine where the side seal grooves have a depth-to-width ratio, a constant radius of curvature and need to have a very smooth side wall texture. Cylindrical end milling cutters have been found not to be rigid enough for the seal high ratio of groove depth-to-width and conventional flat circular milling cutters cannot meet the specifications because they overcut the groove.

A milling cutter suitable for the method of the present invention and which is capable of satisfactorily meeting these requirements has an axis of rotation and radially-projecting, circumferentially-spaced teeth, each tooth having a peripheral cutting edge, the cutting edge lying on a conical surface whose vertex is intersected by said axis. The ends of each peripheral cutting edge are spaced from the vertex at distances equal to the radii of the groove's opposite side walls. The cutter teeth also have side cutting edges on opposite axial sides and these side edges are parallel to one another and spaced apart a distance equal to the groove width. These side cutting edges have either a curvature with radii from a common point on the cutter axis which intersect the cutting edge ends are straight and perpendicular to the peripheral cutting edges. In milling a groove the cutter axis is arranged to intersect an axis which extends through the centre point of curvature of the groove and is parallel to the groove side walls. In addition the cutter axis is tilted at an angle which has the peripheral cutting edges parallel to the work surface and the side cutting edges perpendicular thereto. The cutter is then fed into the workpiece to the required groove depth while the intersection of the cutter axis and groove axis and also the stated angularity is maintained. Then the cutter axis is fixed and the workpiece is turned about the groove axis to effect milling the length of the groove.

Such a milling cutter can be used to mill a curved groove simultaneously cutting opposing sides of the groove without overcutting the top of the groove on one side as the cutter enters and without overcutting the opposite side of the groove as the cutter leaves.

The appended claims define the scope of the invention claimed. How the invention can be performed is hereinafter particularly described with reference to the accompanying drawings, in which:—

Figure 1 is a side view of a rotor in an

internal combustion rotary engine with the rotor having side seal grooves that may be milled by a milling cutter suitable for the method of the present invention;

Figure 2 is a view on a larger scale of such a milling cutter for milling the side seal grooves in the rotor of Figure 1;

Figure 3 is a reduced radial sectional view of the milling cutter of Figure 2 and showing its relationship to the rotor workpiece during milling of a side seal groove, and showing also the relationship of the peripheral edge of one tooth of the cutter to the axis of rotation of the cutter;

Figure 4 is a view of one of the cutter teeth taken along the line 4-4 in Figure 3.

Figure 5 is a view of the one cutter tooth taken along the line 5-5 in Figure 4;

Figure 6 is an elevational view of a machine tool arrangement employing milling cutters according to the method of the present invention for simultaneously machining pairs of side seal grooves on opposite sides of a rotor; and

Figure 7 is a plan view of the machine tool arrangement of Figure 6.

Figure 1 2 shows a milling cutter employed in the method of the present invention for milling the side seal grooves 10 that are on each flat side 12 of a generally triangular shaped rotor 14 of a Wankel type internal combustion rotary engine. The grooves 10 are for receiving side seals, not shown, that seal against the interior end walls of the engine housing. At each rotor apex, adjacent side seal grooves 10 intersect a cylindrical hole 16 which is for accommodating a cylindrical button seal member, not shown, which contacts one of the engine's interior end walls and provides a sealing link between adjacent side seals and an apex seal, not shown, which is carried in a slot 18 extending across each rotor apex, such sealing arrangement being well-known in this engine art.

Each side seal groove 10 and the adjacent face 20 of the rotor has a constant radius of curvature from a common centre point designated at 22 in Figure 1. As shown, the rotor face 20 has a radius R_{20} and the radially inward facing wall 24 and the radially outward facing wall 26 of groove 10 have radii R_{24} and R_{26}, respectively, with the difference in these groove radii being the width W of the seal groove 10. As shown in Figure 3, each groove 10 is rectangular-shaped in radial cross-section with the opposing groove sides 24 and 26 perpendicular to the rotor side 12 and parallel to an axis 27 which intersects the common centre point 22 and is parallel to the rotor's axis 28. The groove's flat bottom 29 is perpendicular to the groove sides 24 and 26 and parallel to the rotor's side 12. The depth of the groove is designated as D.

In general, the machining of a straight groove with a depth-to-width ratio greater than 2:1 presents a tooling problem primarily in attempting to provide a cutting tool of sufficient strength and the problem is enhanced in the case of curved grooves because they impose limits on the peripheral length of a rotary tool and thus limit tool performance. A further problem results where one or more of the groove's surfaces is or are required to be very smooth. For example, in one side seal groove specification, for a rotary engine, it was desired to machine the groove to a depth D of about 0.170 inches and a width W of about 0.040 inches which gave a depth-to-width ratio of about 4:1. In addition to this very high depth-to-width ratio, the groove was to have a radius of about 9.0 inches with a required side wall surface texture having a smoothness greater than 30 micro inches. It was found that conventional milling cutters, such as the cylindrical or the flat circular type, when machining in an arc failed to meet either the specifications of the groove or the short machining time and tool performance necessary for practical high volume production.

A milling cutter employed in the method of the present invention is capable of meeting these requirements. Figures 2 to 5, show such a circular milling cutter 30 capable of machining in the rotor 14 the side seal grooves 10 having the specifications previously described. The circular milling cutter 30 which may also be called a milling or rotary saw is rotatable about a central axis 31 in the direction indicated by the arrow in Figure 2 and has a plurality of equally circumferentially spaced teeth 32. Each of the cutter teeth 32 has a tip having a peripheral leading cutting edge 36 and a trailing relieved portion 37. All of the peripheral cutting edges 36 of the teeth are formed to lie on a conical surface whose vertex 38 is intersected by the cutter axis 31 as shown in Figure 3. It is to be noted that Figure 3 employs the drafting convention of zig-zagging the lines indicating various radii and axes which will be described later, the zig-zagging indicating that these lines have been shortened to enable the drawing to be fitted within the confines of the sheet. The ends 39 and 40 of each peripheral cutting edge 36 are spaced from the groove axis at distances equal to the radii R_{24} and R_{26} of the groove's opposing side walls 24 and 26, respectively, and thus the peripheral cutting edges 36 have a length equal to the width W of the groove 10 to be machined. Each of the cutter teeth 32 also has on opposite axial sides parallel side cutting edges 42 and 44 which extend from the peripheral cutting edge ends 39 and 40 radially inward a distance greater than the groove depth D. The side cutting edges 42 and 44

have trailing relieved flanks 46 and 48, respectively, and may be either curved or straight as will now be described.

In the curved side cutting edge embodiment of the milling cutter, the cutting edges 42 and 44 are formed to lie on notional spherical surface which have a common center that is intersected by the cutter axis 31 and by radii R_{42} and R_{41} which intersect the cutting edge ends 39 and 40 and thus are slightly larger than the groove side wall radii R_{24} and R_{26}, respectively. With such side cutting edge curvature, the milling cutter may be described as a spherically shaped milling cutter. Alternatively, in the straight side cutting edge embodiment of the milling cutter, the side cutting edges 42 and 44 are parallel and are formed to lie on conical surfaces having axially spaced vertexes lying on an extension of the cutter axis 31 with the cone angle determined so that these straight side cutting edges are perpndicular to the peripheral cutting edges 36. With this side cutting edge form, the milling cutter may be described as a conically shaped milling cutter.

To machine a groove, the cutting axis 31 is arranged to intersect the groove axis 27 and is tilted at an angle θ as illustrated in Figure 3 with respect to a line 49 that intersects the cutter axis 31 and is perpendicular to both of the side cutting edges 42 and 44 at points spaced at half of the groove depth, i.e. D/2, from the peripheral cutting edges 36. At the angle θ the peripheral cutting edges 36 as they pass the surface to be machined are parallel thereto while the side cutting edges 42 and 44 are perpendicular to the surface during the pass. The milling cutter 30 while being powered to rotate is then fed into the rotor workpiece in a direction perpendicular to the surface to the required depth. Then the workpiece is turned about the groove axis 27 while the angle θ is maintained whereupon the rotary cutting action of the cutting edges 36 mills the length of the groove. Since the cutting edges 36 lie on a conical surface, these edges inherently track the groove's curvature as compared with a cutter whose cutting edges lie on a cylindrical surface and which would inherently track a straight path rather than the groove's curvature. Thus, the milling cutter 30 with its inherent curved tracking action performs free cutting of the curved groove. When the groove is milled with a conically shaped milling cutter, both of the groove sides 24 and 26 are perpendicular to the rotor side and groove bottom; however, when a spherically shaped milling cutter mills the groove, the radially outward facing groove wall 26 is cut perpendicular like with the conically shaped milling cutter, but the radially inward facing groove wall 24 is slightly undercut in the lower half due to the convex curvature on this cutter side which interferes with cutting a perpendicular wall. The other side of the spherically shaped cutter is convex with respect to the groove wall 26 and thus does not interfere with full straight cutting of that side. The gas pressures in this rotary engine always act to force the side seal against the radially outwardly facing side wall 26 and thus the slight undercutting on the opposite side wall that results from the spherically shaped milling cutter embodiment can be acceptable for such use. The number of cutter teeth will be based on the type of material being machined and its state at the time of machining. Furthermore, the milling cutter can be made from a high speed tools steel or the actual cutting tooth portions may be made from carbide, whichever is best suited to machine the particular material.

Another advantage provided by milling cutters described above is found in the machining of these side seal grooves wherein it is desired not to have the seal groove intersect the button seal hole wall at the other side since such overcutting adversely affects sealing at these locations. The diameter of the milling cutter can be made small enough so as not to bridge the button seal holes at the beginning and ending of a cutting pass. For example, in the previously discussed side seal specifications where the groove has a depth of about 0.170 inches and a width of about 0.040 inches, the attendant button seal holes for the structure have a diameter of about 0.44 inches. A milling cutter having a radius of about 0.390 inches satisfactorily performs the groove cutting operation along its entire length from one button seal hole to the other but does not bridge the larger size button seal holes at the groove ends and thus does not cut into the wall of the button seal holes opposite the intersection of the groove and the seal hole.

Figures 6 and 7, show a milling machine arrangement 50 for using milling cutters according to the method of the present invention. The machine is generally of the carousel type having a platform 51 which supports a rotary table 52 for rotation about a spindle 53. The rotary table 52 in turn supports a fixture 54 for pivotal movement about a spindle 55. A rotor workpiece 14 whose side seal grooves are to be milled is loaded on the fixture 54 and is located relative thereto by a plug 56 in the centre hole of the rotor and a pin 58 in the button seal hole opposite the grooves to be machined, both the plug 56 and pin 58 fitting holes in the fixture 54. With the rotor 14 thus properly positioned, it is then fixed firmly in place by suitable means. In this case, not one but two parallel side seal grooves are

to be cut in each side of the rotor 14. For such machining operation, there are provided three milling machine stations each of which has a pair of milling cutters 30 mounted on arbors 60 of motorized spindles 62 that are arranged to be located on either side of the rotor on slides 64. The slides 64 are supported on a slide carrier 66 to move the milling cutters toward and away from the work. In addition, the axes of the spindles 62 are pivotable to position the milling cutters at the proper angle relative to the workpiece. This inclination is measured relative to the side of the rotor to be machined with the angle point of origin coincidental with the axis of the grooves which is located to coincide with the axis of the spindle 55 about which the fixture 54 can pivot, this angularity positioning the acting peripheral cutting edges of the cutters parallel to the rotor side and the acting side cutting edges perpendicular thereto.

Describing now a typical sequence of events, a rotor 14 is loaded on the rotary fixture 54 when the table 52 is in a load position as shown in Figure 7. The table 52 is then rotated or indexed by suitable means to a first machining location where one of the milling cutter arrangements 50 is located. At this location, one of the button seal holes 16 in each rotor side is aligned with the milling cutters 30. Both sets of cutters while being powered to rotate are then advanced by suitable means at a rapid speed to a certain distance from the rotor surface and from this point the cutters are fed at a reduced rate into the rotor to the required groove depth. When the cutters are at full depth the fixture 54 is pivoted about the spindle 55 by suitable means with the pivoting of the fixture 54 and thus the length of cut continuing until the button seal hole at the approaching apex is reached. Upon reaching this other button seal hole, the cutters are retracted from the groove and the table 52 is indexed to position the rotor whose one set of grooves have just been machined in a second machining location 50 where there is another machine cutter arrangement. As the table 52 indexes to the second machining location, the fixture 54 is returned to its initial position and the rotor 14 is indexed about its axis relative to fixture 54 by suitable means to position the rotor for the machining of another set of grooves at the second machining location in the same manner as performed at the first machining location. The table 52 is then indexed to a third machining location 50 while the fixture 54 and the rotor 14 are indexed for milling of the third set of grooves by the third machine cutter arrangement. In addition there are three groove inspection machines 70 at first, second and third groove inspection locations respectively circumferentially spaced about the platform 51. These inspection machines may be of any suitable type that is operable to inspect the grooves for width and depth of cut and surface texture with the rotating table 52 and fixture 54 indexing the rotor 14 as in the machining operations properly to locate the grooves in relation to these inspection machines for the inspection. After the final inspection location, the table 52 indexes to an unloading position to complete the machining and inspection cycles for all of the side seal grooves in the rotor.

WHAT WE CLAIM IS:—

1. A method of simultaneously milling grooves in opposite sides of a workpiece, in which the grooves have a common centre line, each groove has a bottom and two parallel sides perpendicular to the groove bottom, the two sides having different radii of curvature relative to the common centre line, the method comprising: supporting a milling cutter at each side of the workpiece for rotation about an axis inclined to the common centre line, such that teeth on the cutter having their peripheral cutting edges inclined to the axis of rotation of the cutter will have parallel contact with the sides of the workpiece; rotating the cutters in opposite directions; moving the cutters relative to the workpiece and parallel to the common centre line of the grooves until the peripheral cutting edges on the cutters cut the grooves to the required depth; and turning the workpiece about the common centre line of the grooves to effect simultaneous cutting of the length of the grooves.

2. The method according to claim 1, in which the cutting edges of the milling cutter lie on a conical surface whose vertex is on an extension of the axis of rotation of the cutter.

3. The method of simultaneously milling grooves in opposite sides of a workpiece, substantially as hereinbefore described with reference to and as shown in Figures 6 and 7 of the accompaying drawings.

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Chartered Patent Agent.

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1,365,439 COMPLETE SPECIFICATION
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SHEET 1

FIG.1.

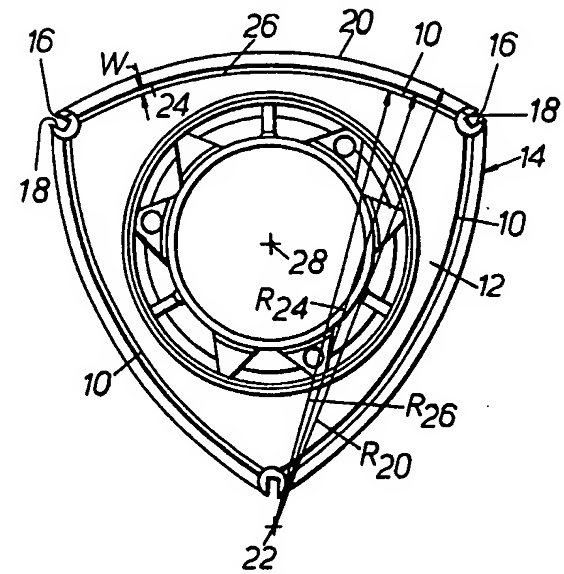
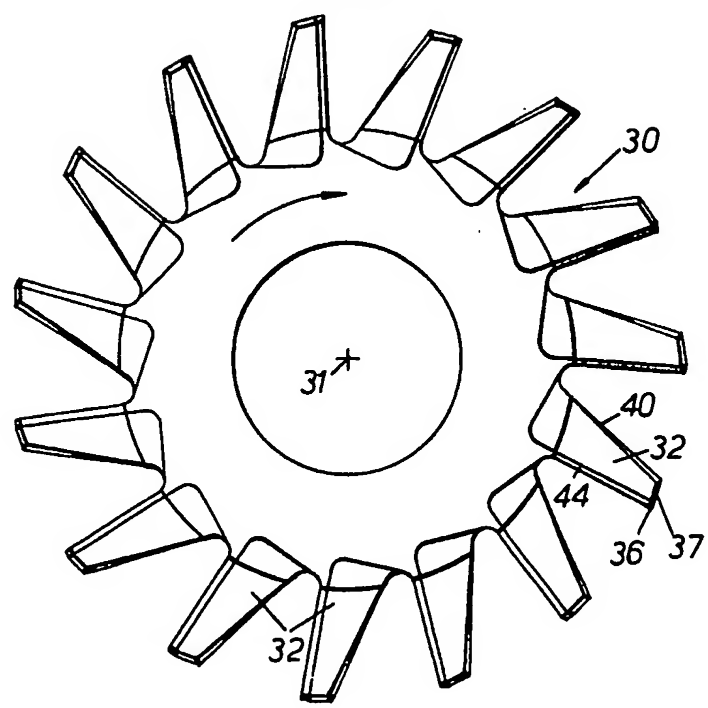


FIG.2.



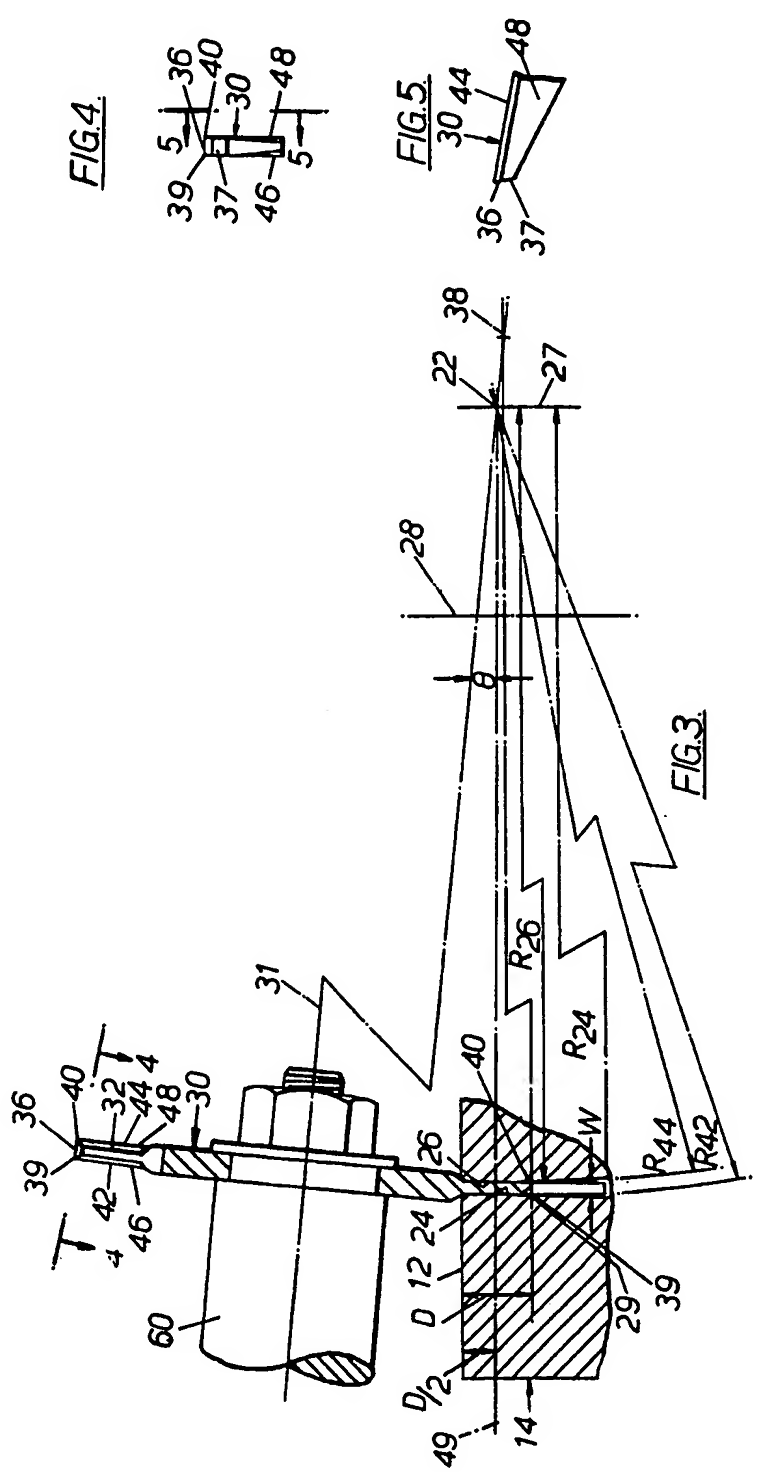


FIG.4.

FIG.5.

FIG.3.

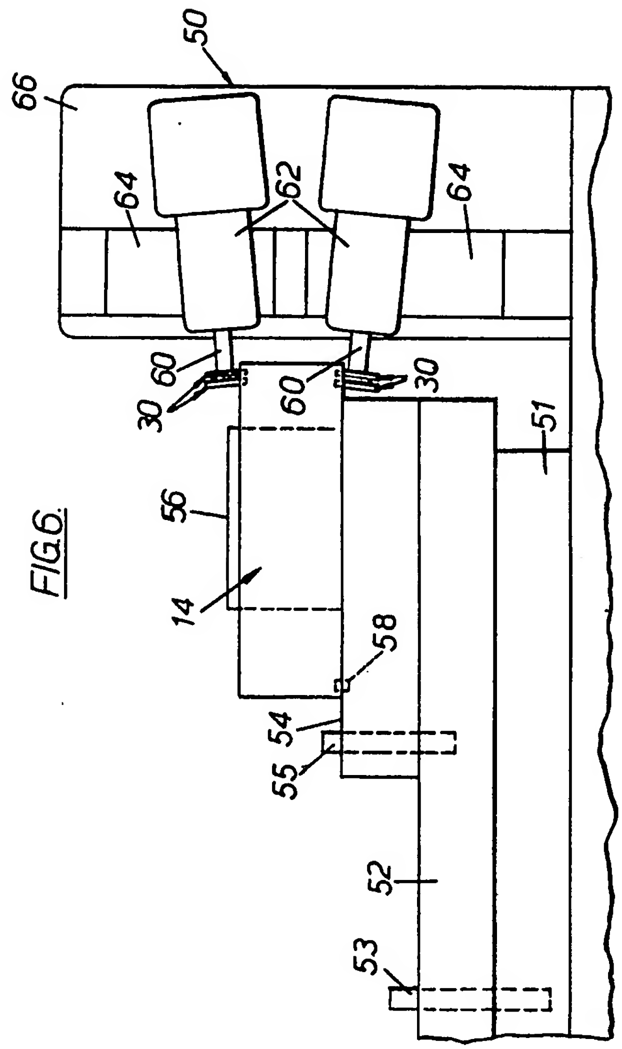
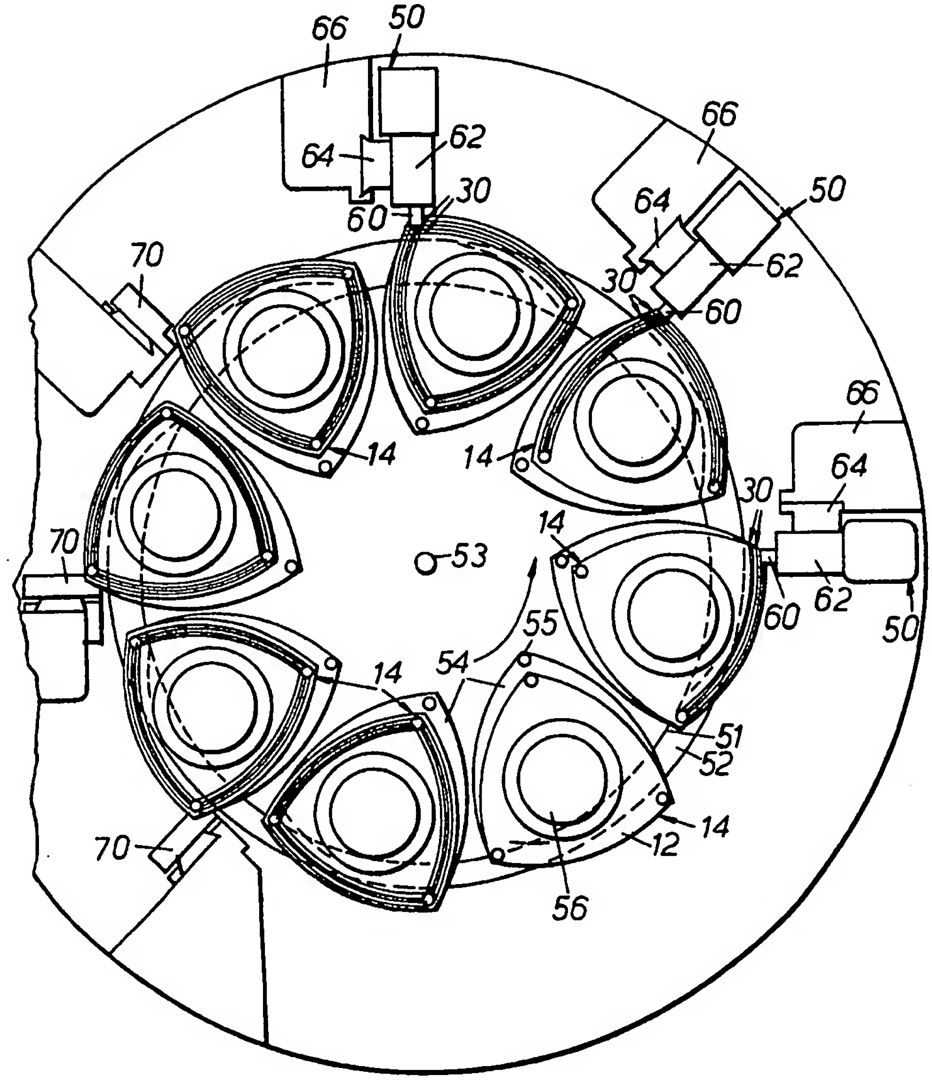


FIG.6.

FIG.7.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